

RETENTION OF RESIN RESTORATIONS BY MEANS
OF ENAMEL ETCHING AND BY PINS

by

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INTRODUCTION

A popular means of restoring fractured anterior teeth is through the use of pins with direct filling acrylic resin. The use of pins decreases the need for extensive removal of the tooth structure to gain retention; but, in turn, the placement of a pin increases the chance of pulpal injury. The possibility of pulpal injury is particularly great since tooth fractures usually occur in individuals from 8 to 11 years of age¹ and the pulp chamber is close to its maximum size at this time. Another disadvantage of pins is their possible interference with the esthetics of the restoration, especially when the tooth has a thin labio-lingual dimension.

Lingual force may be a realistic means of evaluating the retention of different cavity designs since during mastication in the typical Angle's Class I occlusion the mandibular incisors direct a force toward the lingual of the maxillary incisors. Also, Winders² points out that the lingual musculature can develop four times the force of the perioral musculature.

An adhesive restoration material would alleviate the need for pins. It would be of great advantage if the material bonded to enamel and dentin, was capable of withstanding oral stresses, and was tooth-like in appearance. A material of this nature is not yet available but a means of increasing adhesion of currently available direct filling resins has been investigated.

Lee³ has shown that adhesion of an acrylic restorative resin to bovine enamel is increased when the enamel is pretreated with 50 per

cent phosphoric acid. However, Hanke⁴ did not find the adhesion to dentin to be markedly increased by pretreatment with 50 per cent phosphoric acid. This would indicate that in repair of fractured teeth, there is a greater chance of increasing the adhesion of the acrylic resin when the preparation is maintained in the enamel surface.

Doyle⁵ has advocated the clinical use of 50 per cent phosphoric acid in the pretreatment of the enamel for the restoration of fractured anterior teeth without use of pins. He describes the cavity preparation to be employed in restoring these fractures. Regenos⁶ also has advocated enamel etching with a 50 per cent phosphoric acid in restoring fractured anterior teeth without the use of pins. However, there has been no actual evaluation of various cavity preparations or comparison of the relative retention obtained when pins are employed for retention of the restorations.

Such an investigation would therefore seem to be in order. The purpose of this research was to compare the retention of a conventional direct filling resin restoration placed with no pretreatment of the enamel, with pretreatment of the enamel with a solution of 50 per cent phosphoric acid, and with retentive pins. Tests were conducted on four different cavity preparations. Retention of the restorations was evaluated by resistance to displacement under a lingual load.

REVIEW OF LITERATURE

The review of the literature will be separated into two sections:
I - Etiology and incidence of anterior fractures, and II - Treatment
of anterior fractures on permanent centrals.

I - Etiology and incidence of anterior fractures

In 1941 Kramer⁷ reviewed the records of 11,500 Kansas high school students who were in the Athletic Accident Benefit Plan, from 1939 to 1940. A total of 691 injuries were reported that required a physician and dentist for treatment. Of these, 184 or 27 per cent were dental injuries, including 104 broken teeth, 33 chipped teeth, and 24 evulsed teeth. At this time the chance to receive a dental injury in high school sports was one in 60, with football and basketball involved in 97.8 per cent of these injuries.

In 1953 Hallet¹ reported on 670 patients in Newcastle, England who had a total of 1000 fractured teeth, of which 411 occurred in boys and 259 in girls, to give a boys-to-girls ratio of 1.6 to 1. He found that between 8 to 11 years the teeth were very vulnerable to fracture and that the greatest number of injuries occurred at 9 years of age. There were 234 patients with superior protrusion of the anterior teeth and 436 patients free of protrusion. From these patients Hallet calculated that patients with protrusion were nearly five times as vulnerable to fracture of the anterior teeth.

In 1954 Hardwicke⁸ evaluated the records of 160,000 Birmingham children to find 403 patients with 608 fractured teeth. Over a twelve-month period 364 of these fractures occurred in 243 patients, with 50

per cent between the ages of 6 to 16. There were 6.8 per cent of these fractures in enamel, 67 per cent in dentin, and 22.7 per cent involving the pulp. Four per cent of the patients had indicated a previous traumatic injury on one or more occasions. Sixty-eight per cent of the fractures occurred when there was undue prominence of the affected tooth accompanied by no contact in the lower arch. Hardwicke felt that these protruding anterior teeth were frequently accompanied by open lips, mouth breathing, or a history of thumbsucking. Brauer⁹ also suggested that the lack of adequate lip coverage might contribute to the results of traumatic injury.

In 1959 Grundy¹⁰ in England evaluated 625 children from 5 to 15 years of age. Of these patients 32 had fractures for a 5.1 per cent incidence. The boys had 71.9 per cent of the fractures, twice as many as the girls.

In 1959 Lewis¹¹ investigated the relation of protrusion to fractures. He evaluated 343 Caucasians in San Jose, California between the ages of 8 and 13. There was no attempt to select the individuals used in the study. Maxillary incisors with an overjet of 4 mm. were classified as protrusion. Of the 343 patients 17.8 per cent had fractures. When the patients with fractures were compared with those classified as protrusive, he said, "A statistical analysis of the data by means of the Chi Square test suggested that there was a real relationship between the incidence of fractured anterior teeth and the protrusion of those teeth." Lewis also attempted to measure the lip length but found that the patients

assumed a false relationship during attempts to measure them.

In 1959 Murdock¹² evaluated 1,766 children in the Seattle public school system between the ages of 8 and 11. There were 250 children with fractured teeth, of whom 55 had two or more fractures for a total of 311 fractured teeth. The incidence of patients with fractured teeth was 14.2 per cent and the incidence of teeth fractures was 17.6 per cent. Eighty-one per cent of the fractures were in the maxillary anterior teeth, with 59.9 per cent involving the dentin.

In 1961 Davis¹³ evaluated 1,643 children between the ages of 8 and 11 from Washington's Wenatchee public school system and reported that 211 or 12.8 per cent of the children had fractured teeth, including 51 patients with two or more fractured teeth. Each age group demonstrated a different incidence of fractured teeth. The 8-year-old children had 30 fractured teeth, of which 17 occurred in males and 13 in females; the 9-year-olds had 48 fractured teeth, 27 in males and 21 in females; and the 11-year-olds had 82 fractured teeth, 54 in males and 29 in females. A total of 133 fractures occurred in males, an 8.1 per cent incidence; and 78 occurred in females, a 4.7 per cent incidence. Davis classified any fracture as an enamel fracture when it was difficult to determine whether it involved dentin. Fractures involving only enamel occurred in 105 or 40.1 per cent of the patients and fractures involving enamel and dentin occurred in 157 or 59.9 per cent of the patients. A diagonal fracture occurred in 216 or 82.4 per cent of the patients and a horizontal fracture, across the crown,

occurred in 46 or 17.6 per cent of the patients. Of the 211 fractures, only 20 or 9.5 per cent had a restoration placed. In 1962 Finn¹⁴ reported that four per cent of all school children had injured anterior teeth and 80 to 90 per cent of them occurred in the upper central incisors. He also felt that 80 per cent of all oral accidents occurred in or around the home.

In 1963 Eichenbaum¹⁵ reviewed the dental histories of 206 teeth in children between the ages of 6 and 16. In the group of patients with an Angle's Class I occlusion and no protrusion of the teeth, four teeth or 9 per cent were injured out of a total of 44 traumatized teeth, and in patients with protrusion 44 teeth or 78 per cent were injured out of a total of 56 traumatized teeth. In the group of Angle's Class II occlusion, 87 teeth or 84 per cent were injured out of a total of 103 traumatized teeth. An Angle's Class I or Class II occlusion accounted for 95 per cent of all the injuries (131 out of 138), and 82 per cent of all teeth in protrusion were injured when struck. November and March were the peak months for dental injuries which resulted in fractured teeth. Eichenbaum classified protrusion as the "Accident Prone Dental Profile" and said that the severity is in direct ratio to protrusion.

Craig¹⁶ in Edinburgh in 1966 to 1967 found that in an examination of 17,831 children between the ages of 4 to 18, 5.9 per cent had traumatized anterior teeth.

In 1967 Gelbrier¹⁷ carefully evaluated case histories from

February 1964 to June 1966 to find 86 children between the ages of $6\frac{1}{2}$ to 15 years who had fractured teeth. Forty-eight patients sustained two or more injured teeth for a total of 141 injured teeth. The boys-to-girls ratio was 1.9 to 1, and 79 per cent of the injured children were between 7 and 10 years. He found that 24.4 per cent of the patients had declared a history of a previous injury. Fractures involving only enamel occurred in 24.8 per cent of the patients and fractures involving dentin and enamel occurred in 57.6 per cent. Pulpal involvement was present in 17.6 per cent of the patients. The month with the highest number of traumatic injuries was November, with 17 per cent of the total.

In 1967 Parkin¹⁸ in Britain evaluated 94 cases of trauma to find no real change in the incidence of trauma over the past 10 years. This disagreed with Ellis¹⁹ who felt there had been an increase. There were 60 boys and 34 girls between the ages of 7 and 9 who sustained injury. A total of 161 teeth were traumatized with 44 root canals or pulpotomies performed, 6 teeth luxated, and 17 requiring extraction.

In 1969 Boundy²⁰ surveyed 48 patients and found a total of 53 injured teeth, including 40 maxillary incisors and 13 mandibular incisors. The most vulnerable time appeared to be between the ages of 6 and 9. Sports was the single greatest cause of injury, with a total of 14 injuries.

In 1970 Ellis and Davey¹⁹ reported on a 5-year survey by the Department of Physical Education for Public Schools in the Township of Scarborough, Canada. The data were collected by the teachers and

principals. They evaluated 216,000 children to find 6,860 accidents of which 8.1 per cent had obvious involvement of the teeth. Fifty-six per cent of the injuries occurred between the ages of 8 and 11, and for all ages almost 70 per cent of the dental injuries were experienced in boys. The authors also reported on a recent survey in several Canadian secondary schools covering 4,251 children and found that 178 or 4.2 per cent of the children had 205 fractured teeth. The ratio of boys to girls was 127 to 51 or $2\frac{1}{2}$ to 1. Craig¹⁶ pointed out that a further analysis of this study showed that 73 per cent of the fractured teeth were maxillary incisors, 18 per cent were mandibular incisors, 3 per cent maxillary laterals, and 6 per cent mandibular laterals.

None of the previous studies was designed with any uniformity in methods of observation or method of recording, thus making it almost impossible to correlate and make comparisons of their values.

This portion of the literature review indicates a need to determine proper methods of treating and restoring fractured teeth. The following section reviews the different methods of treating fractured teeth.

II. Treatment of anterior fractures on permanent centrals

The first step in treating any anterior fractured tooth involves recording an accurate history and completing a thorough examination by using diagnostic aids.^{9,20-25} Establishing the diagnosis associated with fractured teeth is the initial objective and once this is established, some form of treatment may be considered.

O'Sullivan²⁶ and Heslin²³ have described three phases of restorative

treatment, apart from any endodontic treatment; 1. An emergency phase, 2. An intermediate phase, and 3. A final phase.

The emergency treatment of fractured teeth will vary depending on the degree of injury. A simple enamel fracture may require no treatment or smoothing of a sharp edge.¹⁹ When the fracture exposes dentin, the emergency treatment is designed to protect the pulp against undesirable chemical, thermal and mechanical irritants.²² When the dentin is exposed from a small fracture, Brauer⁹ suggested in 1950 that phenol be placed over the dentin followed by a layer of varnish. The patient is then reexamined in one month for placement of a temporary restoration. Ellis¹⁹ in 1970 suggested placing one or two coats of varnish or fluoride phosphate solution. Ellis acknowledged that this film of varnish would not last indefinitely but he expected it to last long enough for the pulp to recover sufficiently from the stage of shock to withstand most normal oral stimuli.

A larger fracture may require a sedative dressing over the exposed dentin. Both zinc-oxide eugenol and calcium hydroxide have been recommended.^{19,27-30} Starkey²⁹ could find no conclusive evidence that one material is superior to the other and thus recommended the use of calcium hydroxide to eliminate the presence of eugenol, which could interfere with the polymerization of the resin.

Banding and crowning are the two basic methods of retaining sedative dressings. Dannerberg³¹ feels that a band is best used if the fracture is limited to the incisal one-third or one-half of the

tooth, for this is where the bands were designed to fit. If the fracture goes beyond the middle of the tooth a crown may be the restoration of choice.

As a good temporary restoration, a preformed stainless steel band has been recommended by many authors.^{21,24,26,28,29,31-35}

After the preformed band is positioned on the tooth, a piece of band material is contoured over the fractured incisal edge and spot welded to the preformed band. Other authors^{16,23,26,32,33,36,37} describe a similar design, a circumferential band with a tab over the fractured incisal area that may be contoured from aluminum tubing or copper tubing.

When the fractured tooth involves considerable tooth loss, complete coverage with a stainless steel crown, an acetate crown, or celluloid crown may be considered.³⁸⁻⁴²

Authors differ on how long the temporary coverage should remain on the fractured tooth. Brauer⁹ recommended temporary coverage for 3-6 months, Olsen⁴³ 3-4 months, O'Sullivan²⁶ 6-8 weeks, Dietz⁴⁷ 4-6 weeks, and McDonald²⁸ 4-6 weeks or "until recovery of the dental pulp is reasonably evident."

After a convalescent period, the fractured tooth may receive a more substantial restoration. The intermediate phase should provide a durable and esthetic replacement for the lost dental tissue. Law⁴⁵ has established some basic requirements in restoring fractured young permanent incisors:

1. The preparation must be such that it will not endanger the pulp.
2. It should not increase the mesiodistal width of the original tooth or the labiolingual dimension.
3. It should be durable and functional.
4. It should be as esthetic as possible.

Heslin²³ also calls the second phase the "temporary-permanent phase" and feels that the main objective of this phase is to have a minimum tooth reduction with adequate protection and satisfactory esthetics when possible. To attain this objective he has listed some factors to consider:

1. The size and shape of the tooth.
2. The size and shape of the pulp.
3. The extent and position of the fracture.
4. The occlusion.
5. The gingival condition.
6. The importance of appearance.

Various types of transitional restorations are used in the intermediate phase.

There is very little research data to support any one of the following restorations that could be used as a transitional restoration, but all of the following restorations have been suggested because they have been successfully used clinically.⁴⁸ They may be divided into four basic groups: 1. Full coverage or crown restorations, 2. Inlay restorations, 3. Pin retained restorations, and 4. Acid etch retained

restorations.

Full coverage

Down,²¹ O'Sullivan,²⁶ Heslin,²³ McDonald,²⁸ and Finn¹⁴ have recommended the open-faced stainless steel crown as a temporary-permanent restoration. The stainless steel crown usually requires interproximal reduction to allow placement and to help prevent placing an oversized crown. A stainless steel crown is fitted in the accepted manner with the labial portion of the crown being removed for esthetics. The amount of metal visible in the gingival, incisal, and interproximal areas would vary with each restoration. After cementation the fractured area could be filled in with an esthetic restorative material.

Gold, porcelain, and acrylic are also used in placing full coverage of the temporary-permanent restorations. Heslin²³ described a shoulderless preparation for placing a gold or acrylic crown. Law⁴⁵ described a crown preparation for porcelain and acrylic using a feather edge margin. He also described a preparation with a 1-1½ mm. labial reduction for placing a crown with porcelain bonded to gold. Dannenberg,⁴⁹ Daniels,⁵⁰ and Larate⁵¹ recommended placing an all acrylic crown with a full shoulder preparation. Ellis¹⁹ noted that one disadvantage of the acrylic crowns was the lack of stimulation for the laying down of secondary dentin but gave no data to support it. Dannenberg⁴⁹ felt that acrylic crowns were too bulky.

Another good temporary-permanent restoration is the 3/4

9,19,26,28,33,34,45,49,52,53 crown. Ellis¹⁹ felt that this technique was a good compromise in tooth conservation and esthetics without sacrificing function. There is minimal incisal and interproximal reduction. The mesial and distal are either prepared for pin ledges or proximal grooves. Usually there is also a lingual pin ledge parallel to the interproximal. The fractured area is then filled in with a self-cure resin or silicate cement for esthetics.

The basket crown or basket clasp inlay is designed for minimal tooth removal.^{21,32,41,43,44,49,54-57} The lingual and incisal are relieved enough for occlusion and the interproximal reduction is kept to a minimum. To aid retention of the crown, a band of gold is fabricated to go around the labiogingival of the tooth.

Inlay restorations

When indicated, inlays provide a more conservative method to restore fractured teeth since they require less tooth reduction than full coverage or three-quarter crowns. Law⁴⁵ and O'Sullivan²⁶ said that the porcelain inlay can be effectively used in restoring some fractures. Other authors^{19,21,26,38,45,58,59} feel that regular inlays may suffice. When retention is a problem some authors^{9,19,26,28,32} use pins with the inlay.

Pin restorations

A currently accepted method to reduce the need for tooth reduction is to employ pins for retention. Liatukas⁶⁰ describes the use of .022 stainless steel orthodontic wire in retaining silicate restorations

placed on fractured anterior teeth. A single penetration is made into the incisal portion of the remaining tooth with or without proximal involvement. The grooves for retention may be placed in the labial-pulpal and lingual-pulpal line angles as the situation permits. If there is a single point of contact between the tooth and the pin, the pin has to be cemented in place but if the area can receive a multi-branched pin there is no need to cement the pin. Silicate cement is used to restore the fractured area.

Many authors^{16,29,45,47,49,61-69} employ pins in retaining anterior resins. Dietz⁴⁷ describes a method of restoring badly broken down anterior teeth by bending 20-22 gauge gold wire to the tooth contour and cementing it to place. A resin is then placed by the brush technique.

Dannenbergs³¹ emphasizes the importance of placing pins away from the pulp.

Kanter and Kanter^{61,70} describe the use of an "L" shaped pin for retaining anterior resins. The "L" shaped pin is formed and then cemented into place. These authors also suggested the use of a lingual lock as a possible method to retain the resin. They feel that the "U" shaped pin is more difficult to construct and offers no additional advantages over the "L" shaped pin.

Dogan²⁷ evaluated 340 resin restorations placed on permanent anterior teeth over a three-year period. A straight threaded pin or lingual dovetail, as large as practical but no deeper than a 35 inverted

con bur, or both, were used in placing an Addent restoration. At the end of three years 6 per cent of the restorations had to be replaced due to recurrence of trauma or gross discoloration or loosening during function. He feels that these results make this restoration a good long-term temporary restoration (1-5 years).

Acid etched retained resins

Buonocore,⁷¹ Lee,³ Laswell,⁶ and others^{72,73} have demonstrated that the attachment of resin to enamel could be strengthened by pretreating the enamel with phosphoric acid.

Doyle⁵ describes the method of placing a resin on acid etch enamel. He feels that a resin restoration may be retained if the fractured area is limited to the incisal corner. He does not recommend an acid etch resin if the major portion of the incisal edge is fractured. He uses 50 per cent phosphoric acid placed in contact with the tooth for 45 seconds followed by flushing with water and then drying. A cavity primer is placed prior to placing the resin.

Regenos⁶ describes placing resin by the acid etch technic on a fractured maxillary incisor. He does not recommend the use of sealer. However, Lee³ has shown a statistically significant increase in adhesion when the sealer is used. Regenos⁶ feels that if the fracture is minimal the area of fracture needs only to be etched and a resin placed, but if the fracture involves one-half of the incisal portion of the tooth the results are not routinely successful. When the fractured area was small, only four of his first 87 restorations failed

and of these one was retreated successfully. He also describes the use of acid etch resins in hypoplastic teeth or labial defects.

The acid etch retained resin allows a temporary-permanent restoration to be placed with minimal tooth removal. Bennett⁵⁷ said, "To insure that vitality is maintained only minimum tooth should be removed."

A good review of the literature pertaining to the acid etching techniques was presented by Lee.³ His research showed that pretreating the enamel with a solution of 50 per cent phosphoric acid increased the adhesion or retention of the material to the enamel surface.

This review of literature on fractured teeth indicates a need for a comprehensive evaluation to determine how the adhesion or retention gained from etching the enamel surface with phosphoric acid might best be used in a preparation and how it compares to pin retention.

None of the reported investigations evaluated the retention of acrylic restoration placed on fractured incisors. Cavity preparation as related to the repair of fractured teeth with the acid etch retained restorations has not been investigated. There also appears to be conflict among the different authors with respect to the use of single or multiple pins for retention. This research has been designed to answer some of these questions.

METHODS AND MATERIALS

For organizational purposes the methods and materials section has been divided into two parts: Part I - Retention of direct filling resin in four different cavity preparations. Part II - Pin retention of direct filling resin in four different cavity preparations.

Part I - Retention of direct filling resin in four different cavity preparations.

This portion of the study evaluated the retention of the resin in four cavity preparations where the restorations were subjected to a lingual force. The retention of a conventional methyl methacrylate direct filling resin was tested in all cavities before and after treatment of the enamel with a solution of 50 per cent phosphoric acid.

Extracted incisors were collected from oral surgeons in the area. They were instructed to place the teeth in water immediately upon extraction. The teeth were cleaned by placing them for 20 minutes in an ultrasonic cleaner with a dilute solution of sodium hypochlorite. The teeth were stored in water at all times when test procedures were not being performed. While the various experimental procedures were being carried out, the tooth was wrapped in a moist absorbent paper to minimize desiccation.

Before the preparations were cut, each tooth had one incisal angle removed to simulate an Ellis's Class II fracture. (This type of fracture involves both enamel and dentin.) The simulated fracture was obtained by drawing a 557 crosscut fissure bur in an air rotor handpiece from the interproximal toward the incisal of the tooth. Standardization

of the instrumentation and cutting technique provided a considerable measure of consistency in the surface roughness. Although the specimens varied to some degree, every attempt was made to keep the surface areas similar in size. After creation of the simulated fractures, the teeth were returned to water for storage until cavity preparation.

Four different cavity preparations were evaluated (Figure 1). The surface areas for individual teeth are seen in Table I. A summary of direct measurements made on the preparation is seen in Table II. Three of the groups evaluated used the flat incisal angle preparation which was the same as the simulated fracture. Group C_1 , Figure 1, was a flat incisal angle preparation on central incisors with an average surface area of flat enamel of 0.00707 in^2 . Group L_1 was a flat incisal angle preparation on lateral incisors with an average of 0.00585 in^2 of enamel available for etching. Group L_2 was an incisal angle preparation on lateral incisors with an average of 0.00483 in^2 of enamel available for enamel etching.

Group C_2 , Figure 1, was a circumferential enamel shoulder preparation with an average surface area of 0.01935 in^2 available for enamel etching. This preparation on ten incisors had an average lingual height of 0.62 mm and lingual depth of 0.35 mm. The average labial height was 0.58 mm and labial depth was 0.44 mm.

Group C_3 , Figure 1, was a lingual enamel shoulder with labial grooves that had an average surface area of 0.0327 in^2 of enamel available for etching. This preparation had an average lingual

height of 1.7 mm and, lingual depth of 0.44 mm and an average labial height of 0.72 mm and labial depth of 0.46 mm. The labial also had two narrow grooves in the preparation that extended gingivally. The groove nearer the interproximal area of the tooth had a height of one to two millimeters and the groove toward the incisal had a height of two to three millimeters.

Group C₄, Figure 1, was a labial enamel shoulder with extended lingual enamel shoulder preparation that was found to have an average surface area in the enamel of 0.0537 in². This preparation had an average lingual height of 3.0 mm and lingual depth of 0.51 mm. The average labial height was 1.6 mm and labial depth was 0.55 mm. The average mesio-distal width of the lingual box was 3.64 mm.

Group C₅ was the same as Group C₂, except that the average labial height was 0.74 mm and labial depth was 0.56 mm and the average lingual height was 0.72 mm and lingual depth was 0.36 mm.

Group C₆ was the same as Group C₂ except that the average labial height was 0.75 mm and labial depth was 0.53 mm and the average lingual height was 0.68 mm and depth was 0.37 mm.

The method of obtaining these measurements will be discussed at the end of this section.

Each experimental group was composed of a minimum of ten teeth.

In each group the same teeth were employed to compare the retention of the restoration when the enamel was untreated and when the enamel was pretreated with a solution of 50 per cent phosphoric acid. Except for

the flat surface groups, all preparations were maintained in the enamel.

A 557 crosscut fissure carbide bur in an air rotor, with air as the coolant, was used to make the preparations in the enamel surface. Attempts were made to prepare the cavity as it would have been performed in the mouth. This was accomplished by maintaining the bur parallel to the long axis of the tooth. Care was taken to avoid the production of undercuts in preparation. After the cavities were cut, the teeth were stored in water until the restorations were placed. Each tooth was restored with a conventional methyl methacrylate direct filling resin.* A small amount of fat red dye was added to the monomer. The pink color aided in the detection of adhering fragments of acrylic and also facilitated finishing the restoration to the cavo-surface margin. Preliminary tests showed that adding this dye did not interfere either with adhesion or polymerization of the resin.

As stated previously, all teeth were first restored without pretreatment (etching) of the enamel surface and the retention of the restoration was evaluated.

After the restorations were dislodged, the cavities were examined under a microscope and all adhering fragments of acrylic removed carefully by means of a chisel. These same teeth were then employed to determine retention of resin restoration when the enamel of the cavity

* Sevrison - Amalgamated Dental Trade Distributors Ltd., London, England

was subjected to a one-minute pretreatment with 50 per cent phosphoric acid. Unless otherwise stated, all teeth were restored with a control restoration prior to testing the experimental restorations. A series of preliminary tests were performed to determine if the placing of a control restoration influenced the subsequent adhesion of the experimental restoration. A statistical analysis of preliminary data showed that the retention of the restorations placed on acid etched enamel was not influenced by the prior placement of control restorations.

Procedure for placing control restoration

As stated previously, all teeth were first restored with no pretreatment of the enamel surface. After the retention had been evaluated without treatment (etching), these cavity preparations were carefully examined under the microscope.

The following is the stepwise procedure employed in the placement of the control restorations (no acid etching):

1. The prepared tooth was wrapped in a moist piece of paper and the crown thoroughly dried with soft paper and a chip blower.
2. A thin layer of Copalite was applied to all exposed dentin by means of a fine camel hair brush (this was done since this step was necessary in the experimental group to prevent the acid from contacting the dentin.)
3. The Copalite was removed from the tooth with a cotton pellet saturated with chloroform. The tooth was then dried

with a chip blower.

4. Sevriton sealer was placed over the entire preparation with a camel hair brush.
5. The restoration was then placed with a fine camel hair brush using a bead-brush technique.²⁹
6. The restoration was built up one to two millimeters above the incisal edge of the tooth to provide an area for the load point of the testing machine to contact the restoration.
7. Sevriton lubricant was placed over the restoration and over the tooth to prevent evaporation of the monomer and excessive dehydration of the tooth. The tooth was allowed to remain in the air at room temperature for 15 minutes and then placed in water at room temperature for a minimum of one hour when the restoration was finished. The finishing was done with a number eight round bur and a fine sandpaper disc using a conventional speed handpiece. Clinical judgment was used in contouring the restoration.
8. The restored teeth were placed in water and stored in an incubator at 37° C for seven days before testing.

Procedure for placing the etched restoration

The teeth were restored in basically the same manner as the control restoration.

1. The tooth was dried thoroughly, and Copalite was placed on exposed dentin. This was done to prevent any injury which

might arise clinically from contact of the dentin by the acid.

2. A solution of 50 per cent phosphoric acid was placed over the entire preparation with a saturated cotton pellet and allowed to contact the tooth for one minute. The surface was then thoroughly rinsed by means of a stream of water.
3. The cavity was dried with a soft piece of absorbent paper and chip blower and the Copalite removed with a cotton pellet of saturated chloroform.
4. The restoration was placed and finished in the same manner as described previously for the control specimens.

Testing retention

Retention was evaluated by applying a lingual force. The tooth was supported on the lower platen of the Rhiele machine in an aluminum holder, Figure 2. The arm projecting from the side had eight screws to adjust the angulation of the crown. These flat tip screws allowed the root to be mounted in such a manner that the lingual surface of the crown and restoration could be positioned parallel to the lower platen of the test machine.

The following method was devised to help standardize the point of loading for an individual tooth in order that the fulcrum distance would be the same in the control and experimental groups. When the tooth was properly positioned in the holder, a pencil line was drawn across the restoration at the height of the incisal edge.

Every attempt was made to have this line perpendicular to the long axis of the tooth. A free-hand pencil line was drawn so that it bisected the preparation and intersected the previous line at a perpendicular angle. The intersection formed a standardized point for application of load. To insure that this distance was standardized, the fulcrum length was measured. The force was applied by means of a specially designed 1 mm diameter metal point secured on the Rhiele machine. A load rate of 0.030 inches per minute was applied to the lingual of the restoration until it was dislodged or fractured.

Each tooth was examined under the microscope to determine the type of failure. If the cavity was free of resin, the failure was listed as "adhesive". If it was completely covered by resin it was listed as a "cohesive failure." If portions of the preparation were free of resin but there were resin fragments in some areas, the failure was recorded as "adhesive-cohesive."

Water storage

The retention in four different cavity preparations was evaluated on central incisors and two preparations on lateral incisors. The four preparations on the central incisors were (1) the flat incisal angle preparation, Group C_1 ; (2) the circumferential enamel shoulder preparation, Group C_2 ; (3) the lingual enamel shoulder with labial grooves, Group C_3 ; and (4) the labial enamel shoulder with extended lingual enamel shoulder, Group C_4 . The two preparations in the lateral incisors were flat incisal angle preparations similar to those of

Group C₁.

Both the control and experimental restorations (where the tooth structure was pretreated with acid) were stored for seven days in water at 37° C.

Temperature stressing

The 10 teeth with the circumferential preparation, Group C₅ (Figure 1), were subjected to thermal stressing after 24 hours in water at 37° C. Using the automatic temperature cycling apparatus, the test specimens were cycled alternately 500 times between two water baths each day for five days. One bath was maintained at 10° C \pm 5° and the other bath at 50° C \pm 5°. The immersion time in each bath was 30 seconds. At completion of the temperature cycling the test specimens were stored in water at 37° C for an additional 24 hours when retention of the restoration was measured.

Mechanical stressing

Ten central incisors with the circumferential preparation, Group C₆ (Figure 1), were stored in water at 37° C for seven days and then subjected to intermittent mechanical stress.

In subjecting the specimens to intermittent mechanical stress the specimens were oriented in the testing machine in the same manner as for testing retention of the restorations. A load of 10 pounds was applied to the restoration at a cross-head speed of 0.050 inches per minute, released, and then reapplied. After the specimen had been stressed 60 times it was loaded at a cross-head speed of 0.030 inches

per minute to failure.

Measurement of substrate

As stated previously, when tests were completed a series of measurements were made of the four different preparations to determine the surface area of the enamel of the preparation so that retention of the restoration could be related to surface area and also to determine the variation in the area of a given preparation from tooth to tooth within each experimental group. The prepared enamel surface areas of Group C₁, C₂, C₃, I₁ and I₂, were measured. This permitted calculation of the stress (psi) placed upon the surface area of enamel, required to produce failure.

To determine the total surface area of the preparations in Groups C₂, C₃, and C₄, platinum foil was adapted into the preparation and trimmed along the cavosurface margin. A second piece of foil was adapted to the preparation and trimmed as before. The two pieces of foil were weighed separately on an analytical balance to the nearest one-tenth milligram and the weights of the two pieces averaged. The average weight was then compared to that of a piece of foil of the same thickness and of known surface area. The total surface area of the preparation (both enamel and dentin) was calculated by comparing the weight of the foil adapted to the preparation with that of foil with a known surface area.

A second step was then necessary to determine the surface area of the enamel. The tooth was placed under a dissecting microscope and the dentin portion of the preparation was colored in by a sharp

lead pencil. A colored slide was then produced using a constant object - film distance. This was accomplished by placing the teeth beneath a glass slide held in a fixed position and then photographing them with a camera whose position also was fixed. The resulting slides were then projected onto a paper at a known magnification. The outline of the dentin was traced onto the paper. The area of the dentin surface was determined on this tracing by a planimeter. The surface area of the enamel in the preparation was obtained by subtracting the surface area of the dentin from the total surface area of the preparation as obtained with the platinum foil.

In the case of the flat preparations, Groups C₁, L₁, and L₂, it was not necessary to employ the step involving the platinum foil since the surface area of the enamel could readily be determined by the photographic procedure.

Some additional measurements were made of the cavity preparation to determine if the amount of resin present influenced results, and if so, in what manner.

Each preparation was measured directly with a modified Boley gauge to determine the depth and height in different areas. The height of the preparation refers to the incisal gingival height and the depth refers to the distance from the cavosurface margin to the depth of the preparation in a buccal or lingual direction. The specimen was held under a dissecting microscope (10 X) so that the contact and angulation of the Boley gauge extension could be controlled.

In Groups C₂, C₃, C₄, C₅ and C₆ the height was measured at two points on the labial, and two points on the lingual. One point was toward the incisal portion of the preparation and the other was toward the gingival portion. The incisal height and depth also were measured and in the circumferential preparation, Group C₂, the gingival height was measured in the middle of the interproximal preparation. The average values obtained from these measurements may be seen in Table II.

Part II - Pin retention of direct filling resin to four different preparations.

This phase of the study evaluated the relative ability of pin resin restorations to resist a lingual force. The teeth used in the first series of tests were used in this portion of the study.

Any adhering acrylic was removed from the preparation and the enamel portion was gone over lightly with rotary instruments to remove any etched enamel and to expose a fresh surface. The cutting instrument employed was that used to prepare the enamel surface in initial cavity preparation. However, conventional speed was used here rather than high to assure minimal removal of tooth structure. All specimens were examined under the dissecting microscope at a magnification of 10X to be sure that no dentin had been exposed.

In experimental Group L₂ the resin restoration was retained with one "L" shaped pin. The gingival pin hole was placed with 0.027 spiral drill to a depth of 2-3 mm.* The length and angulation of the "L"

* Measured with an Omni-depth gauge, Waledent, Inc., Brooklyn, N.Y.

shaped pin placed for maximum retention were based upon clinical judgment and hence to some degree depended upon the preparation.

All pins were cemented with zinc phosphate cement using 1.6 gm of powder mixed in the accepted manner on a cooled glass slab with 0.05 cc of zinc phosphate liquid.

A spiral drill was used to fill the pin hole prior to forcing the 0.025 serrated pin to the depth of the pin hole. Excess cement was removed with a chisel and the surface was cleaned with chloroform on a cotton pellet. The resin restoration then was placed by a bead brush technique. After seven days storage in water at 37° C the resistance of the restoration to dislodgement by a lingual force was determined. The testing procedure was the same as in Part I.

In Group C₂ and C₃ the retention of the resin restoration was evaluated both with one and two pins.

The retention of the single "L" shaped pin was placed and evaluated as described above for Group L₂. After the retention was tested with the single pin, the restoration and pin were removed by twisting and applying pressure. Once the pin and acrylic were removed, a second pin hole was placed in the incisal area of the preparation at an angle and height commensurate with the tooth anatomy. The previously placed gingival pin hole was cleaned, and two straight pins were then cemented into the holes. The lengths of these pins depended upon the size and shape of the preparations.

The cavities were then restored with the resin storage in water

for seven days at 37° C, and the retention of the restorations was tested.

In Groups C₁ and C₄ the retention of the restoration placed with two pins was evaluated. The gingival and incisal pin holes were placed in the same manner as for C₂, C₃ and L₁. These restorations also were tested at the end of seven days.

RESULTS

The results of tests on specimens stored in water at 37° C for seven days are summarized in Figure 3. A statistical analysis of these data was performed to determine: (1) the significance of the differences in retentive values obtained by pretreatment of the teeth with acid and the use of retentive pins; and (2) the significance of the differences in retentive values obtained for restorations placed in the cavity preparations of four different designs.

An analysis of variance⁷⁴ was performed which indicated a significant difference between groups (cavity preparations of different design) and between methods of obtaining retention of the restoration. The group differences do not follow the same trend for control, acid-etched enamel, and two retentive pins. Neither do the differences for method of retention follow the same trend for the four cavity preparations. Therefore further analysis of the data was required. The Newman-Keuls' sequential range test⁷⁴ was performed to test for differences between any two groups within each method, and between any two methods within each group.

The summary of the statistical analysis appears in Table III.

Flat incisal angle preparation

The results of tests comparing the retention of resin on flat cavity preparations on central incisor teeth (Group C₁) as influenced by pretreatment of the enamel surface with phosphoric acid and by the use of two serrated stainless steel pins are seen in Table IV and Figure 3.

Pretreatment of the enamel with the acid significantly increased the retention of the resin in this cavity preparation. The average resistance to the lingual force in the control group (untreated enamel) was 3.02 ± 1.76 lbs. (441 ± 81 psi). An average force of 9.07 ± 2.36 lbs. (1324 ± 147 psi) was required to dislodge the restorations placed on acid-etched enamel.

The resistance recorded for pin retained restorations was the maximum force observed when a snap was heard and the needle on the testing machine immediately dropped, indicating a loss of resistance.

When the acrylic restorations were retained with two straight pins, dislodgement was accomplished with an average lingual force of 17.90 ± 4.07 lbs. Two pins offered twice as much resistance to the force as the restorations placed on acid-etched enamel.

Some additional work (Table V) was done using a single "L" shaped pin for retention of a resin restoration on lateral incisors (Group L_1). An average lingual force of 3.26 ± 0.64 lbs. was required to dislodge the restorations. The restoration rotated intact around the axis of the cemented pin. A force of 7.99 ± 4.02 lbs. was required to dislodge the restoration placed on the acid etched enamel on the same teeth; thus the single pin was only half as resistant to the lingual force. The resistance of the single pin was not significantly different from the resistance of the control restorations placed on the centrals. The results on the retention of resin restorations placed on the lateral incisors (Group L_2) are seen in Table VI and Figures 3 and 4. The

average resistance to a lingual force of the control restoration (no pretreatment) was 2.68 ± 1.12 lbs. (571 ± 76 psi) while an average of 5.96 ± 1.69 (1443 ± 196 psi) force was required to dislodge the restoration when the enamel was etched with acid. Retention of the restoration was significantly increased by pretreatment of the enamel with the acid but there was no significant difference between the resistance of the control restorations and the single pin retained restorations (Group L_1).

Careful examination of the control teeth (no etching) in both series, C_1 and L_2 , indicated that all failures were in adhesion. In no instance could fragments of the resin be detected on the tooth structure. When the enamel was pretreated with the 50 per cent phosphoric acid, all except one restoration exhibited an adhesive-cohesive break. One adhesive failure occurred in Group L_2 and none in Group C_1 . In most specimens the acrylic remained on the gingival portion of this flat preparation. There were minor variations in the amount retained by different specimens.

From the photographic evaluation it was determined that Group C_1 had a surface area of 0.00707 in^2 and Group L_2 had a surface area of 0.00483 in^2 . Despite this difference in surface area between Groups C_1 and Groups L_2 , there was no significant difference in the magnitude of the lingual force required to dislodge the restorations.

With respect to the type of failure, with pin retained restorations one remained intact but was pulled away from the lingual margin while

the other nine fractured at the incisal pin and rotated in the gingival pin hole.

Circumferential enamel shoulder preparation

The results of tests to determine the resistance to a lingual force of restorations placed in circumferential preparations are seen in Table VII and Figures 3 and 4.

The control restorations (untreated enamel) were dislodged by a lingual force of 2.36 ± 1.36 lbs. (159 ± 42 psi). This is not significantly different from the results obtained in the previous series of test preparations (Groups C_1 and L_2). The restorations placed on the acid pretreated enamel surface failed under an average force of 23.93 ± 3.08 lbs. (1465 ± 228 psi). This value was significantly greater than that obtained for the flat preparations (Groups C_1 and L_2) pretreated by acid.

All control specimens failed in adhesion. All the acid-etched retained restorations exhibited adhesive-cohesive breaks. In all specimens the greatest portion of retained acrylic was on the gingival portion of the preparation. The next largest bulk of material was retained on the lingual. In many cases there was a thin film of acrylic on the labial in the line angle of the preparation.

After evaluation of restorations placed on pretreated enamel, the 10 teeth were tested using a single "L" shaped pin for retention of the resin. These restorations offered an average resistance to a lingual force of 14.71 ± 1.98 lbs. This was not significantly different from

the resistance offered when the flat preparation was restored with a resin restoration retained by two pins. The single pin retained restoration was significantly higher in resistance than the restoration placed on etched enamel in Group C₁ and significantly lower than the resistance offered by Group C₂. When the enamel was pretreated the lingual ledge of acrylic fractured and the restorations rotated around the pin.

The same teeth then were evaluated when two straight pins were used for retention. The restorations retained with two pins afforded an average resistance to a lingual force of 23.35 ± 3.08 lbs. The resistance of the restoration retained by two pins is comparable to that of the retention when acid pretreatment was employed. It was significantly higher than Group C₁ restorations placed on pretreated enamel. It was slightly higher in its resistance to a lingual force than restorations placed on the flat preparations with two retentive pins. In four out of the ten teeth, the restoration fractured in the area of the incisal pin. The other six restorations remained intact but pulled away from the tooth at the lingual margin.

Lingual enamel shoulder with labial grooves

The results of tests to determine the retention of resin restorations placed in a preparation with a lingual enamel shoulder and labial grooves are presented in Table VIII and Figures 3 and 4.

The control restorations (untreated enamel) required application of a lingual force of 4.93 ± 2.03 lbs. (153 ± 18 psi) to accomplish

dislodgement. This was not significantly different from previous control groups. Acid-etching of the preparation again increased the resistance of the restorations to displacement. After the cavities were etched a force of 26.18 ± 4.43 lbs. (834 ± 76 psi) was required to displace the resin restoration. This value is higher than that obtained for the acid pretreated flat preparations (Groups C_1 and L_2) but not significantly different from results obtained for the etched circumferential preparation in Group C_2 .

In all but two instances some resin was retained in the labial extension of the preparations in control teeth. The acrylic that was retained could be easily flaked away by a pointed instrument.

In all restorations placed on pretreated enamel there was an adhesive-cohesive break. In 10 of the 11 specimens a layer of acrylic extended from the lingual to the gingival portion of the preparation. In acid-etched specimens both the lingual portions of the preparation and the labial grooves were filled with resin.

After testing of the etched specimens, restorations were placed and retained with a single "L" shaped pin. These restorations afforded an average resistance to a lingual force of 18.35 ± 5.33 lbs. These data were not significantly different from those obtained for either the single or double pins in the circumferential preparation or from the acid-etched retained restoration in Group C_2 . It was significantly higher than the acid-etched flat specimens.

In six of the 11 restorations in this group retained by the single

pin, the acrylic remained intact and pulled from the lingual margin while on the remaining four teeth the resin fractured in the lingual area. None of the restorations rotated as did the restorations in other cavities when retained by a single pin.

When two straight pins were used for retention of the resin restorations, the restorations failed with an average load of 16.96 ± 5.06 lbs. This was not significantly different from the pin retained restorations in Group C₁, and the single pin in this group or from the acid-etched specimens in Groups C₂ and C₃. It was significantly greater than the pretreated enamel on the flat preparation and all of the controls.

In seven of 11 teeth the acrylic remained intact but pulled away at the lingual margin. The remaining four restorations fractured in the area of the incisal pin.

Labial enamel shoulder with extended lingual enamel shoulder

The results of tests comparing the retention of resin restorations on a labial and lingual shoulder preparation are shown in Table IX and Figures 3 and 4.

The control restorations (untreated enamel) demonstrated an average resistance of 6.89 ± 2.22 lbs. (128 ± 13 psi) to the lingual force. This resistance was not significantly different from any other controls. Acid etching of the enamel increased the resistance to displacement. An average force of 31.64 ± 7.26 lbs. (589 ± 42 psi) was required to dislodge the restorations. This was significantly higher than the control specimens in this group. The value also was

significantly higher than those obtained for any other experimental groups.

All 10 specimens in the control group failed in adhesion. All restorations in acid-etched series exhibited adhesive-cohesive failures. In all instances the acrylic adhered to labial and lingual portions of the preparation. Acrylic remained in the lingual box in all specimens. Generally more acrylic was retained on the preparation in this group than in other types of preparations.

After the effects of the acid-etching had been tested, this preparation was evaluated using two straight pins for retention. An average lingual force of 16.46 ± 5.01 lbs. was required to produce failure. The resistance was not significantly different from the double pins in Group C_1 , the single pins in Group C_2 , and the single and double pins in Group C_3 but the resistance was mathematically lower than the double pin in Group C_2 . It was significantly greater than the flat etched specimens (Group C_1 and L_1) and all controls.

In seven of 10 specimens the restorations fractured in the area of the incisal pin while the remaining three restorations remained intact but pulled away from the lingual margin of the preparation. In three instances the enamel fractured in the area of the incisal pin.

Temperature Stressing

The results of tests on Group C_5 to determine the effect of temperature stressing on the retention of resin in the circumferential

enamel shoulder preparation are presented in Table X and Figure 3. All specimens were stored in water at 37° C for 24 hours before and after five days of temperature stressing as outlined.

All control specimens (untreated enamel) survived 2500 temperature cyclings over a period of five days. The control restorations were then dislodged with an average lingual force of 5.62 ± 1.59 lbs. The cavity preparation in Group C₅ was the same as for Group C₂ and these data were not significantly different from those for controls in Group C₂. Average lingual force of 23.99 ± 4.6 lbs. was required to dislodge the thermal cycled restoration placed on the etched enamel surface. Again this was not significantly different from data for etched specimens of Group C₂.

Mechanical Stress

The results of tests on Group C₆ to determine the effects of mechanical stress on the retention of resin in the circumferential enamel shoulder preparation are presented in Table XI and Figure 3. After seven days' storage in water at 37° C these restorations were subjected to 60 cycles of an intermittent mechanical shear stress outlined previously.

None of the control specimens survived the stress cycling at a pre-set load value of 10 lbs. This would be expected since the average value for the control specimens stored in water for seven days was below this value.

With respect to restorations placed on acid-etched enamel, one

specimen fractured during stress cycling and was recorded as zero. However, the average force required to dislodge these restorations after stress cycling was 18.87 ± 8.02 lbs. Again this was the same preparation as in Group C₂. Apparently the mechanical stress cycling had little or no effect upon retention since the force required to dislodge the restoration was not significantly different from comparable specimens tested after seven days storage in water. As before, all controls failed in adhesion while all failures of pretreated specimens were of the adhesive-cohesive type. The cause for the failure of the one specimen during cycling is not known.

TABLES

TABLE I

Surface Area Per Square Inch

	C_1	C_2	C_3	C_4	L_1	L_2
1	.00812	.0314	.0378	.0609	.00498	.00320
2	.00591	.0203	.0325	.0512	.00503	.00568
3	.00615	.0079	.0357	.0541	.00605	.00507
4	.00740	.0200	.0211	.0525	.00712	.00456
5	.00763	.0258	.0241	.0517	.00451	.00380
6	.00715	.0154	.0293	.0554	.00675	.00500
7	.00605	.0264	.0210	.0525	.00726	.00542
8	.00948	.0203	.0341	.0539	.00606	.00567
9	.00673	.0173	.0376	.0506	.00523	.00563
10	.00609	.0087	.0404	.0546	.00426	.00404
11			.0408		.00719	.00516
Average	.00707	.0194	.0327	.0537	.00585	.00483

TABLE II

Average of the Measurements From Direct Evaluation
of the Preparation's Depth and Height

Average of	C ₂	C ₃	C ₄	C ₅	C ₆
Lingual height	0.62	1.70	3.00	0.72	0.68
Lingual depth	0.35	0.44	0.51	0.35	0.37
Labial height	0.58	0.72	1.60	0.74	0.75
Labial depth	0.44	0.46	0.55	0.56	0.53

TABLE III

Summary of statistical analysis conducted to compare the retention of restorations in the four cavity preparations. There is no significant difference between the values which are underlined.

Method of Retention	Retention-Pounds Force			
	C ₁	C ₂	C ₃	C ₄
Control	<u>2.36</u>	3.02	<u>4.93</u>	<u>6.89</u>
Acid etch	9.07	<u>23.93</u>	<u>26.18</u>	31.64
2 pins	<u>17.90</u>	23.35	<u>16.96</u>	<u>16.46</u>

Summary of statistical analysis conducted to compare the retention of restorations as related to the method of retention. There is no significant difference between the values which are underlined.

Cavity Preparation	Retention-Pounds Force		
	Control	Acid Etch	2 Pins
C ₁	3.02	9.07	17.90
C ₂	2.36	<u>23.93</u>	<u>23.35</u>
C ₃	4.93	26.18	16.96
C ₄	6.89	31.64	16.46

TABLE IV

Flat Incisal Angle Preparation - Seven Days In Water At 37° C

Group C₁*

Specimen Numbers	(lbs.)	Control (psi) (type of break)	(lbs.)	Acid Etch (psi) (type of break)	Two Pins (lbs.)
1	4.6	577 A	7.7	948 AC	18.5
2	2.7	457 A	10.3	1743 AC	20.2
3	3.0	488 A	7.6	1236 AC	13.5
4	5.9	797 A	15.0	2027 AC	26.0
5	0	0 A	7.9	1035 AC	17.0
6	0.2	28 A	4.9	685 AC	15.3
7	4.7	777 A	9.4	1554 AC	14.5
8	2.6	274 A	8.1	854 AC	12.5
9	3.3	490 A	7.3	1100 AC	18.5
10	3.2	525 A	12.5	2053 AC	23.0
Average	3.02	441	9.07	1324	17.9
Standard Deviation	1.76	81	2.36	147	4.07

A = Adhesion

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number obtained from the same central incisor

TABLE V

Flat Incisal Angle Preparation - Seven Days in Water at 37° C

Specimen Numbers	Control	Group L ₁ *			Pin (lbs.)
		(lbs.)	Acid Etch (psi)	(type of break)	
1		9.4	1847	AC	2.5
2		2.3	457	A	3.5
3		8.5	1405	AC	4.1
4		17.1	2402	AC	3.0
5		5.0	1109	AC	3.0
6		5.6	815	AC	3.3
7		5.7	785	A	2.2
8		13.3	2195	AC	3.0
9		4.6	880	AC	3.3
10		8.8	2066	A	3.5
11		7.6	1057	AC	4.5
Average		7.99	1365		3.26
Standard Deviation		4.02	199		0.64

A = Adhesive

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number was obtained from the same lateral incisor.

TABLE VI

Flat Incisal Angle Preparation - Seven Days in Water at 37° C

Specimen Numbers	Group L ₂ *					
	(lbs.)	Control (psi)	(type of break)	(lbs.)	Acid Etch (psi)	(type of break)
1	1.9	594	A	3.3	1031	AC
2	3.3	581	A	5.4	951	AC
3	4.4	867	A	4.8	947	AC
4	3.7	811	A	5.8	1272	AC
5	2.4	632	A	9.3	2447	AC
6	2.6	520	A	6.0	1200	AC
7	3.0	554	A	6.7	1236	AC
8	0	0	A	4.0	705	AC
9	2.3	408	A	5.1	2682	AC
10	3.7	891	A	8.2	2030	AC
11	2.2	426	A	7.1	1376	AC
Average	2.68	571		5.96	1443	
Standard Deviation	1.12	76		1.69	196	

A = Adhesive

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number was obtained from the same lateral incisor.

TABLE VII

Circumferential Enamel Shoulder Preparation - Seven Days in Water at 37° C

Group C₂*

Specimen Number	(lbs.)	Control (psi)	(type of break)	(lbs.)	Acid Etch (psi)	(type of break)	One Pin (lbs.)	Two Pins (lbs.)
1	3.9	124	A	32.0	1019	AC	13.5	26.0
2	0	0	A	20.5	1009	AC	14.8	27.2
3	2.9	367	A	24.4	3089	AC	18.5	19.0
4	1.7	85	A	21.5	1075	AC	11.4	21.6
5	2.0	78	A	28.7	1112	AC	14.9	27.5
6	4.9	318	A	29.0	1883	AC	17.9	24.2
7	2.1	80	A	17.1	648	AC	14.3	26.1
8	0.9	44	A	24.0	1182	AC	13.6	20.0
9	1.9	110	A	21.1	1220	AC	14.0	19.8
10	3.3	379	A	21.0	2414	AC	14.2	22.1
Average	2.36	159		23.93	1465		14.71	23.35
Standard Deviation	1.36	42		3.08	228		1.98	3.08

A = Adhesive

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number was obtained from the same central incisor.

TABLE VIII

Preparation With a Lingual Enamel Shoulder and Labial Grooves - Seven
Days in Water at 37° C

Group C ₃ *								
Specimen Numbers	(lbs.)	Control (psi)	(type of break)	(lbs.)	Acid Etch (psi)	(type of break)	One Pin (lbs.)	Two Pins (lbs.)
1	10.1	267	AC	24.3	616	AC	16.7	20.0
2	2.6	80	AC	22.0	677	AC	19.0	11.5
3	4.7	132	AC	26.2	734	AC	24.5	20.0
4	2.7	100	AC	29.5	1089	AC	25.6	20.9
5	4.6	191	AC	26.3	1091	AC	12.1	19.1
6	5.2	177	AC	27.8	949	AC	23.1	25.5
7	4.6	219	AC	25.2	1200	AC	17.5	17.0
8	6.3	184	A	37.3	1087	AC	23.9	15.4
9	6.0	160	AC	22.9	609	AC	16.7	18.4
10	4.7	116	AC	27.0	668	AC	15.0	12.6
11	2.7	69	AC	19.5	466	AC	7.7	6.2
Average	4.93	154		26.18	834		18.35	16.96
Standard Deviation	2.03	18		4.43	76		5.33	5.06

A = Adhesion

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number was obtained from the same central incisor.

TABLE IX

Preparation With a Labial Enamel Shoulder and Extended Lingual Enamel
Shoulder - Seven Days in Water at 37° C

Specimen Numbers	Group C ₄ *						Two Pins (lbs.)
	(lbs.)	Control (psi)	(type of break)	(lbs.)	Acid Etch (psi)	(type of break)	
1	5.8	95	A	36.0	591	AC	11.9
2	4.1	80	A	35.0	684	AC	9.2
3	6.5	120	A	29.8	551	AC	11.7
4	7.1	135	A	21.9	417	AC	17.9
5	5.8	112	A	33.4	646	AC	25.7
6	11.3	204	A	37.5	677	AC	20.4
7	10.3	196	A	26.6	507	AC	15.2
8	4.6	85	A	46.0	853	AC	23.1
9	5.6	111	A	29.8	591	AC	14.7
10	7.8	143	A	20.4	374	AC	14.8
Average	6.89	128		31.64	589		16.46
Standard Deviation	2.22	13		7.26	42		5.01

A = Adhesive

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number was obtained from the same central incisor.

TABLE X

Circumferential Enamel Shoulder Preparation - Temperature Stressing

Group C₅*

Specimen Number	(lbs.)	Control (type of break)	(lbs.)	Acid Etch (type of break)
1	6.0	A	19.8	AC
2	3.5	A	29.6	AC
3	4.7	A	24.4	AC
4	6.9	A	31.1	AC
5	5.3	A	20.4	AC
6	6.3	A	15.4	AC
7	8.9	A	25.7	AC
8	3.1	A	24.1	AC
9	6.2	A	28.0	AC
10	5.3	A	21.4	AC
Average	5.62		23.99	
Standard Deviation	1.59		4.61	

A = Adhesive

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number was obtained from the same central incisor.

TABLE XI

Circumferential Enamel Shoulder Preparation - Mechanical Stressing at 10 Pounds

Group C₆*

Specimen Numbers	Control		Acid Etch	
	(lbs.)	(type of break)	(lbs.)	(type of break)
1	0	A	15.7	AC
2	0	A	21.5	AC
3	0	A	10.6	AC
4	0	A	20.5	AC
5	0	A	22.3	AC
6	0	A	31.2	AC
7	0	A	22.3	AC
8	0	A	22.1	AC
9	0	A	22.5	AC
10	0	A	0	AC
Average	0		18.87	
Standard Deviation	0		8.02	

A = Adhesive

C = Cohesive

AC = Adhesive and Cohesive

* Each value listed following specimen number was obtained from the same central incisor.

ILLUSTRATIONS

Figure 1: Photograph of plaster teeth depicting a labial
 view of the four different preparations evaluated.

- Group C₁ - a flat incisal angle preparation
- Group C₂ - a circumferential enamel shoulder preparation
- Group C₃ - a lingual enamel shoulder with labial grooves
- Group C₄ - a labial enamel shoulder with extended lingual shoulder

 Photograph of plaster teeth depicting a lingual view
 of the four different preparations evaluated.

- Group C₁ - a flat incisal angle preparation
- Group C₂ - a circumferential enamel shoulder preparation
- Group C₃ - a lingual enamel shoulder with labial grooves
- Group C₄ - a labial enamel shoulder with extended lingual shoulder

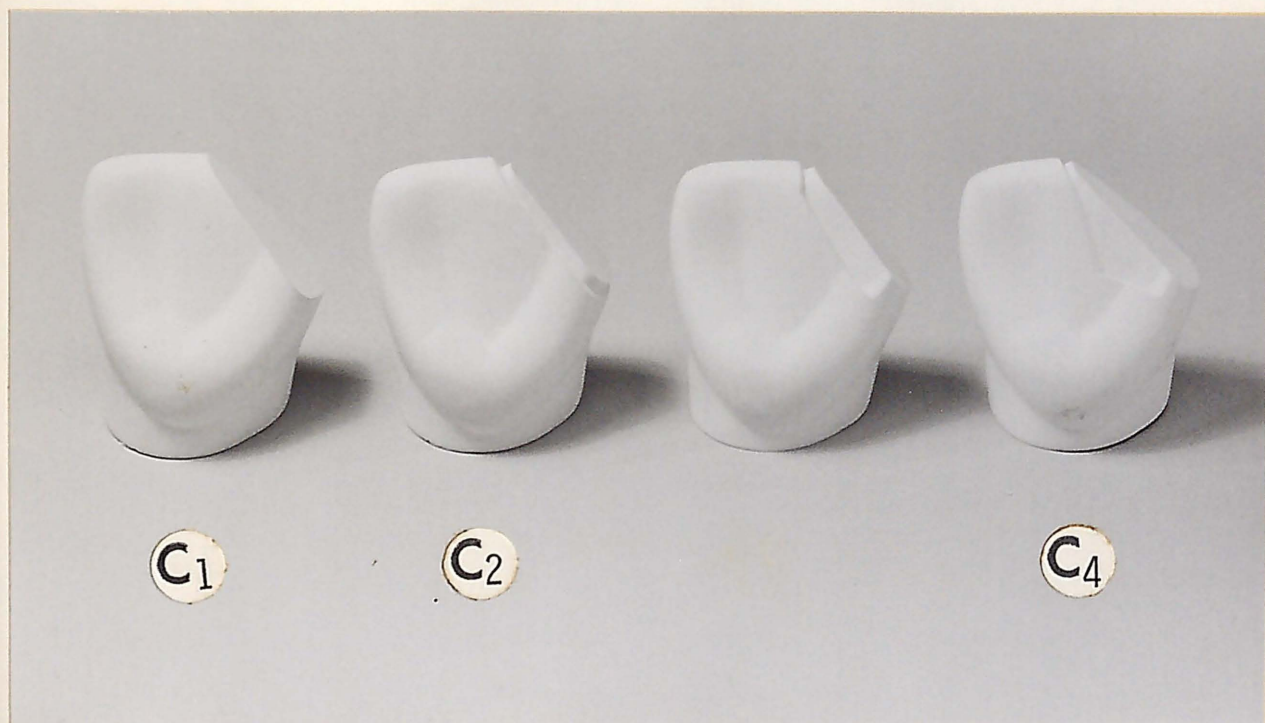
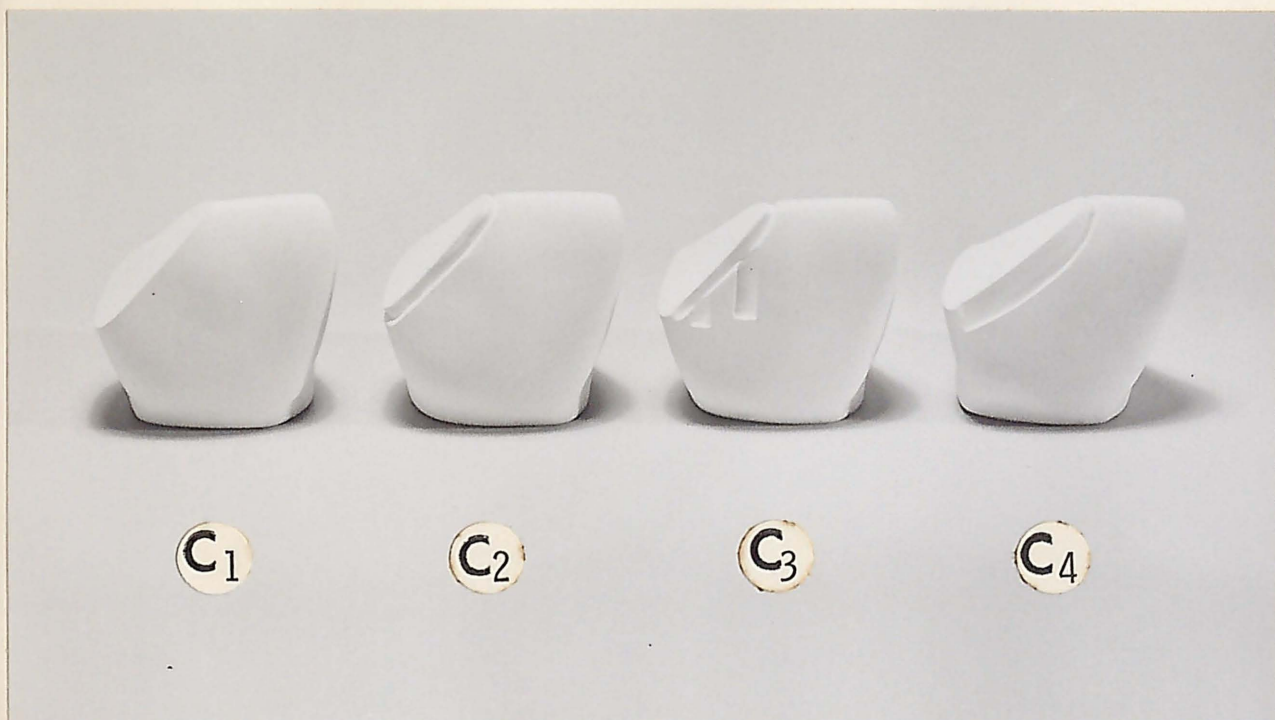


Figure 2: Photograph of central incisor mounted in the test jig. The special metal tip is placed over the point of intersecting lines drawn on the extended finished acrylic restoration. This jig was placed on the platen and the metal cylinder was firmly mounted on the cross arm of the Rhiele machine.

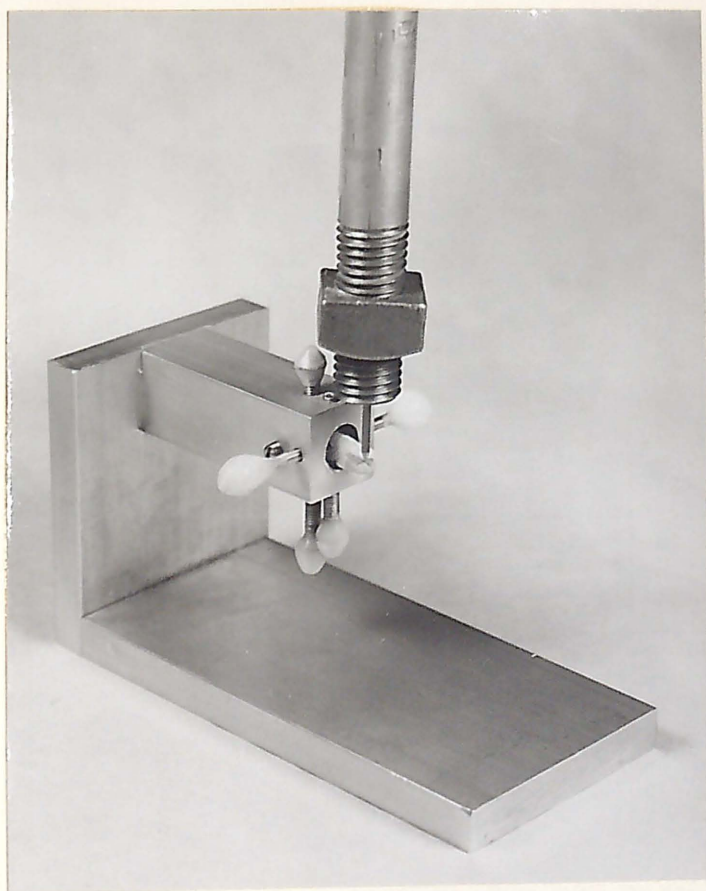


Figure 3: Summary of data on the retention of direct filling resin in pounds after seven days storage in water at 37° C. Group C₅ was subjected to thermal stressing for five days. Group C₆ was subjected to intermittent mechanical stress prior to evaluating the retention.

SUMMARY DIRECT FILL RESIN - 7 DAYS STORAGE IN H₂O

GROUP

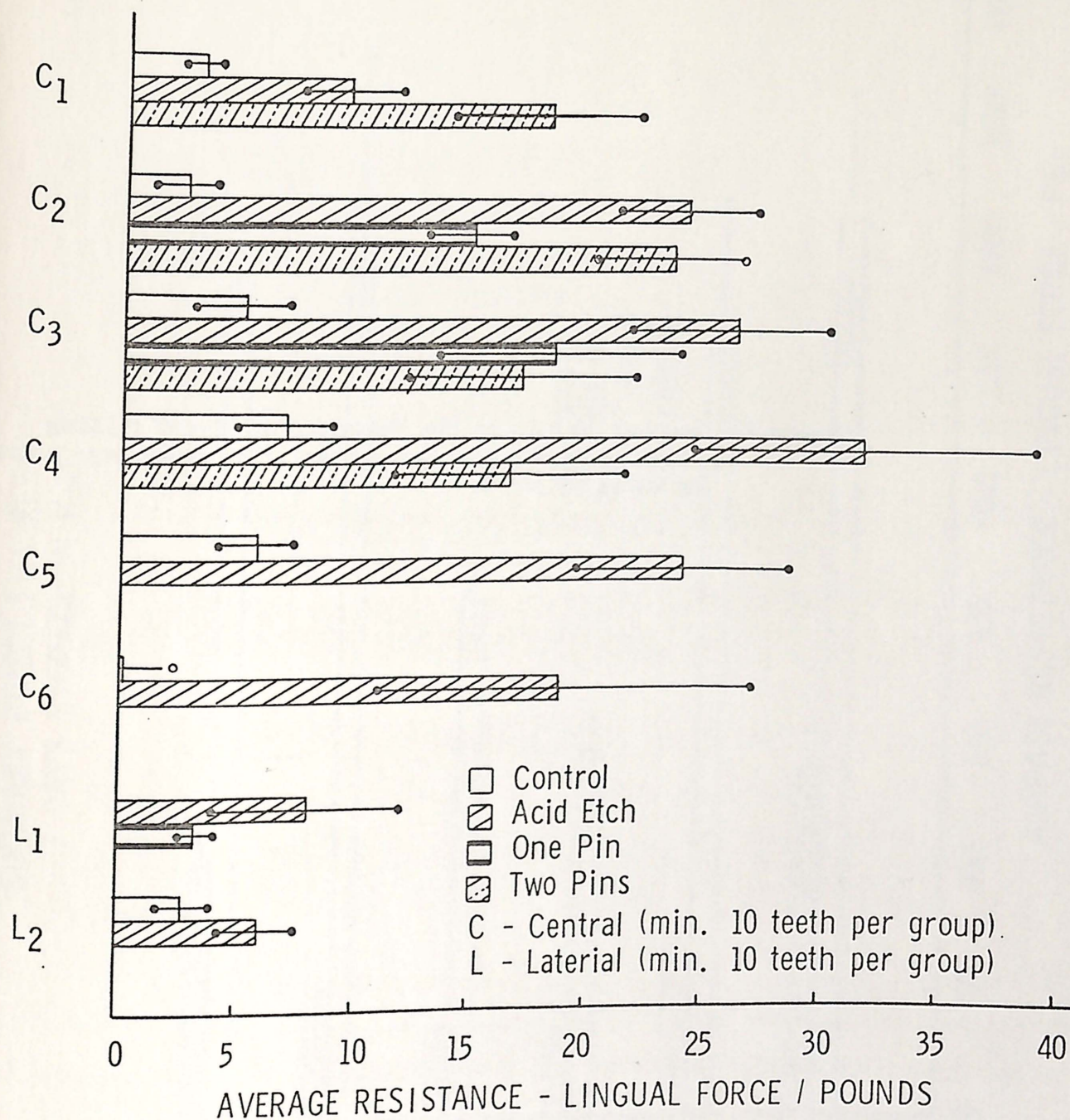
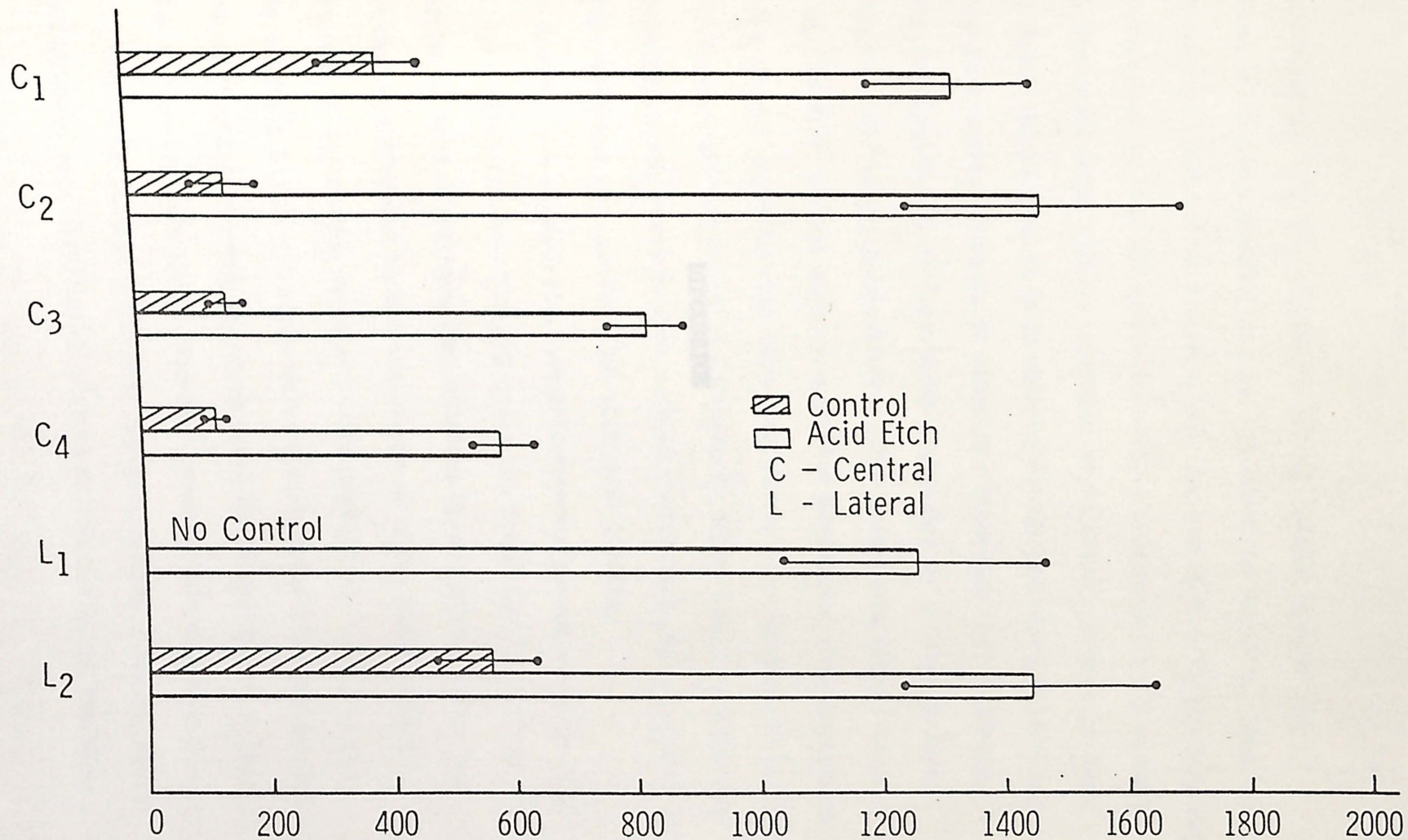


Figure 4: Summary of data on the retention of direct filling resin in pounds per square inch after seven days storage in water at 37° C.

SUMMARY DIRECT FILL RESIN - 7 DAYS STORAGE IN H₂O

GROUP



AVERAGE RESISTANCE - LINGUAL FORCE / PSI

RESISTANCE LINGUAL / PSI

DISCUSSION

In Groups $C_1 - C_4$ the resistance of all control groups was lower than in the experimental groups. However, in Group L_1 , when the restoration was retained by a single pin, the resistance to displacement was not superior to that of controls in other test groups. This would suggest that some other aid in retention is necessary or perhaps that the pin should be secured at both ends to obtain increased retention.

When no auxiliary methods of obtaining retention were employed, there was no significant difference in resistance to a lingual force among the four different preparations. Also when restorations were placed on the flat incisal angle preparation pretreated with phosphoric acid, they showed significantly lower resistance to a lingual force than comparable restorations placed in cavities of other designs. When the flat preparation was restored with a resin restoration retained with two pins, the retention was greater than with acid etching.

In Groups $C_2 - C_4$ when the restorations were placed on acid-etch enamel, the resistance to a lingual force was found to be equal to or superior to that of restorations retained by two pins. There was no appreciable difference in the resistance of other pin-retained restorations in any of the cavities tested here.

The slightly higher retentive value obtained for the acid-etched retained restoration in Group C_4 as compared to Groups C_2 and C_3 may have been due to the fact that a somewhat greater bulk of resin was present. Since the lingual portion of the preparation extended about three millimeters onto the lingual surface of the tooth, it was more

difficult to maintain the standard thickness of acrylic in that area.

With respect to cavity design, when employing the acid-etch technique it would appear to be desirable to prepare at least a one millimeter or greater enamel shoulder on the labial and lingual surfaces to increase the retention of resin restorations. When two pins are used for retention, the cavity design does not appear to influence retention.

The results of this study are in agreement with those of Lee³ and others^{71,72,73} in that the adhesion or retention of a conventional resin restoration can be increased by pretreating enamel with a solution of 50 per cent phosphoric acid. The increase in adhesion created by acid etching of the enamel is in general comparable to the increase achieved by the use of two retentive pins.

When the single pin retained restoration was placed on the circumferential shoulder preparation, the cavity sealer was omitted. Lee³ reported that when the cavity sealer is omitted there is a significantly lower resistance to dislodgement. Thus the omission of the cavity sealer could be responsible for the fact that resistance to a lingual force was lower than in restorations on the same preparation retained by two pins and also the acid etched group. In the other test group, where one and two pins were compared, there was no significant difference in the resistance of the restorations to dislodgement.

The enamel surface area of each preparation increased from

Group C₁ to Group C₄. It progressed as follows: The flat incisal angle preparation, Group C₁, had a surface of 0.00707 in² of enamel; the circumferential enamel shoulder preparation had a surface area of 0.0194 in² of enamel; the preparation of a lingual shoulder with labial grooves had a surface area of 0.0327 in² of enamel; the preparation of a labial enamel shoulder with extended lingual enamel shoulder had a surface area of 0.0537 in² of enamel.

As the enamel surface area available for acid etching increased, the resistance to a lingual force, as measured in pounds, also increased but the calculated pounds per square inch decreased in the last two groups. Upon examination of the latter groups of specimens after testing, it was noted that as the area of the preparation increased the amount of acrylic adhering to the surface of the preparation also increased. Thus fracture occurred in the bulk of acrylic rather than at the interface and for this reason could not be related to the total surface area of the preparation as in the case of adhesive failure. In some teeth the restoration would fracture so that the surface area was similar to the flat preparation. This may indicate that a total surface area of 0.0327 in² or more of enamel provides sufficient surface area to make the adhesion or bond strength of the thin ledge of the acrylic greater than the cohesive strength of the material.

The configuration of this preparation is also important. In the specimens where the height of the preparation was 1.7 mm. or greater, the lingual preparation was almost always completely full of acrylic.

This would suggest that in preparations with a lingual height of 1.7 mm. or more the failure may be more closely associated with cohesion of the material than with adhesion. The thin labial projection on the preparation with a lingual enamel shoulder and labial grooves, Group C₃, afforded no benefit with respect to retention of the restoration. Most of the control restorations in this group also had acrylic remaining in the narrow projection after testing. The remaining acrylic was easily flaked out, indicating that only minimal retention was required to maintain the acrylic in these narrow projections. Thus it would seem that preparations used to increase resistance to dislodgement of a resin restoration placed on pretreated enamel should be other than small or narrow thin projections. To gain the maximum effect from the enamel preparation, it would appear that it should be more of a shoulder type.

A preliminary study evaluated a 2.6 mm. diameter acrylic cylinder using a shear force placed at different fulcrum lengths. The cylinder was held parallel to the platen and the force was applied perpendicular to the cylinder at known fulcrum lengths until the acrylic cylinder fractured. When the fulcrum length was 3 mm. the acrylic cylinder offered an average resistance of 8.8 ± 0.79 lbs. (1078 ± 97 psi) before fracture. When the fulcrum length was 2 mm., the acrylic offered an average resistance of 14.89 ± 2.02 lbs. (1825 ± 250 psi). Comparing the pounds per square inch at the above fulcrum lengths on the acrylic cylinder to the psi resistance of the flat preparation and

circumferential preparation, it appears that the resistance of acrylic placed on pretreated enamel is offering a resistance close to the maximum cohesive strength of the acrylic.

The principal reason that pins are used for retention of anterior restorations is to minimize the need for tooth reduction. When a fracture occurs clinically the surface may be a flat surface tapering to the lingual. Thus the low retentive value for a flat preparation of a single pin suggests that in this situation a single pin does not increase resistance to a lingual force. To increase retention, a 1-1.5 mm. preparation in the enamel on the labial and lingual surfaces may be utilized in conjunction with either single or double retentive pins. Since there was no significant difference between the resistance of restorations retained by two pins and those in a one to two millimeter enamel preparation pretreated with acid, the latter would appear to be an equally good means of retaining the restoration.

The chance for traumatic injury to reoccur may fall between Hardwicke's⁸ findings of 4 per cent and Gelbier's¹⁷ findings of 24.4 per cent. Regardless of the incidence of recurrent injuries, when pin-retained restorations are used there is a chance for further injury to the tooth, for example fracture due to the lateral force on the projecting pin. This was demonstrated in a few of the test specimens when during the application of a lingual force the incisal enamel fractured in the area of the incisal pin. An acid etch technique to retain restorations eliminates the possibility of this type of injury.

The acid pretreatment method eliminates the possibility of the pin involving the pulp or of heat damage to the pulp from pin hole placement.^{75,76}

Not only will the pretreatment of the enamel allow restoring fractured incisors without pins but it also is well adapted to the placement of a temporary-permanent restoration on hypoplastic teeth. Regenos⁶ has advocated placing a 0.5 mm. preparation maintained in enamel around the hypoplastic defect, to be followed by pretreatment of the enamel with a solution of 50 per cent phosphoric acid.

The laboratory data on the retention of resin restorations when a phosphoric acid pretreatment of enamel is utilized are similar to those obtained for pin-retained restorations. As has been indicated, some clinical reports have appeared on the subject. However, there is a need for a well controlled and detailed clinical study to compare the performance of resin restorations retained by pins with those where retention was obtained by pretreating the enamel with phosphoric acid.

SUMMARY AND CONCLUSION

An investigation was conducted with respect to the effect of acid etching of the enamel and the use of pins on the retention of direct filling resins when used for restoration of fractured incisor teeth. The retention secured by these techniques as related to the cavity design also was studied.

Extracted incisors selected from the surrounding area were prepared with four different cavity preparations. Prior to cavity preparation, an incisal angle was removed from each tooth to simulate an Ellis Class II fracture. They were divided into groups consisting of at least 10 teeth. The four cavity preparations were: (1) flat incisal angle, (2) circumferential enamel shoulder, (3) lingual enamel shoulder with labial enamel grooves, and (4) a labial enamel shoulder with extended lingual enamel shoulder. All preparations were maintained in the enamel of the tooth.

Retention of the resin restoration in each of the four preparations was evaluated when: (1) no adjunctive measures to improve retention were employed (control), (2) when the enamel of the preparation was pretreated with acid, and (3) when two retentive pins were employed. Three of the preparations were also evaluated with a single retentive pin. All the groups were tested after seven days storage in water at 37° C. The effect of thermal stressing and mechanical stressing on retention was investigated with the circumferential preparation.

There was no significant difference in retention in any of the preparations restored on untreated enamel. In all four cavity

designs the use of either the acid-etch technique or two pins significantly increased the retention of the restoration. However, when only one "L" shaped retentive pin was employed in conjunction with a flat incisal preparation, the force required to accomplish displacement was no greater than for controls. In the flat incisal angle preparation, the resistance of the restorations retained by two pins was significantly greater than acid-etched retained restorations. In the remaining three preparations the resistance to a lingual force of the restorations placed on acid etched enamel was found to be equal to or superior to that of restorations retained by two pins.

With respect to cavity design, the results of this study indicate that a preparation one millimeter or greater maintained in the enamel and placed on the labial and lingual surfaces provides better retention than does a flat incisal angle preparation.

In the acid etch technique within certain limits the enamel surface area and its distribution are important factors in retention.

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ABSTRACT

Retention of Resin Restorations by Means
of Enamel Etching and by Pins

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An investigation was conducted into the effect of acid etching of the enamel and the use of pins on the retention of direct filling resins when used for restoration of fractured incisor teeth. The retention secured by these techniques as related to the cavity design also was studied.

Four different cavity preparations were used. The retention of the resin in all four was compared when there was no pretreatment of the enamel, when the enamel was etched by 50 per cent phosphoric acid, and when pins were used for retention. Retention was assessed on the basis of resistance of the restoration to displacement by a lingual force. No significant difference was observed in retention as related to cavity design in the control specimens. In all four cavity preparations, acid etching of the enamel and the use of two retentive pins increased the resistance of the restorations to displacement. (However, when only one "L" shaped retentive pin was employed in conjunction with a flat incisal preparation the force required to accomplish displacement was no greater than for controls.) The acid etch technique when employed with a cavity preparation that extended 1.7 mm. or more onto the lingual surface of the enamel generally offered a higher resistance to lingual force than double pin retained

restorations. There was no significant difference between the resistance offered by a circumferential preparation when the resin was retained by either acid etching or by two pins.

In the acid etch technique the enamel surface area and its distribution are important factors in retention.